Inventors: Wayne V. Sorin

TUNABLE DYNAMIC GAIN FLATTENING FILTER USING POLARIZATION DELAYS

Cross-Reference to Related Applications

This application is a continuation-in-part of serial no. 09/765,971 filed 01/19/2001 which is a continuation-in-part of serial no. 09/729,661 filed 12/04/2000, which is a continuation-in-part of serial no. 09/666,763 filed 09/21/2000, which application is a continuation-in-part of and claims the benefit of priority from Provisional Patent Application Serial No. 60/206,767, filed 05/23/2000, serial no. 09/666,763 also being a continuation in part of serial no. 09/571,092 filed 5/15/2000, which is a continuation of serial no. 09/425,099 filed 09/23/1999, which is a continuation-in-part of serial no. 09/022,413 filed 02/12/1998, which claims priority to KR 97-24796 filed 06/06/1997, all of which applications are fully incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to tunable band-rejection filters, and more particularly to tunable band-rejection filters using fixed and tunable polarization delays.

Description of Related Art

In modern telecommunication systems, many operations with digital signals are performed on an optical layer. For example, digital signals are optically amplified, multiplexed and demultiplexed. In long fiber transmission lines,

the amplification function is performed by Erbium Doped Fiber Amplifiers (EDFA's). The amplifier is able to compensate for power loss related to signal absorption, but it is unable to correct the signal distortion caused by linear dispersion, 4-wave mixing, polarization distortion and other propagation effects, and to get rid of noise accumulation along the transmission line. For these reasons, after the cascade of multiple amplifiers the optical signal has to be regenerated every few hundred kilometers. In practice, the regeneration is performed with electronic repeaters using optical-to-electronic conversion. However to decrease system cost and improve its reliability it is desirable to develop a system and a method of regeneration, or signal refreshing, without optical to electronic conversion. An optical repeater that amplifies and reshapes an input pulse without converting the pulse into the electrical domain is disclosed, for example, in the U.S. Pat. No. 4,971,417, Radiation- Hardened Optical Repeater". The repeater comprises an optical gain device and an optical thresholding material producing the output signal when the intensity of the signal exceeds a threshold. The optical thresholding material such as polydiacetylene thereby performs a pulse shaping function. The nonlinear parameters of polydiacetylene are still under investigation, and its ability to function in an optically thresholding device has to be confirmed.

Another function vital to the telecommunication systems currently performed electronically is signal switching. The switching function is next to be performed on the optical level, especially in the Wavelength Division Multiplexing (WDM) systems. There are two types of optical switches currently under consideration. First, there are wavelength insensitive fiber-to-fiber switches. These switches (mechanical, thermo and electro-optical etc.) are dedicated to redirect the traffic from one optical fiber to another, and will be primarily used for network restoration and

reconfiguration. For these purposes, the switching time of about 1 msec (typical for most of these switches) is adequate; however the existing switches do not satisfy the requirements for low cost, reliability and low insertion loss. Second, there are wavelength sensitive switches for WDM systems. In dense WDM systems having a small channel separation, the optical switching is seen as a wavelength sensitive procedure. A small fraction of the traffic carried by specific wavelength should be dropped and added at the intermediate communication node, with the rest of the traffic redirected to different fibers without optical to electronic conversion. This functionality promises significant cost saving in the future networks. Existing wavelength sensitive optical switches are usually bulky, power-consuming and introduce significant loss related to fiber-to-chip mode conversion. Mechanical switches interrupt the traffic stream during the switching time. Acousto-optic tunable filters, made in bulk optic or integrated optic forms, (AOTFs) where the WDM channels are split off by coherent interaction of the acoustic and optical fields though fast, less than about 1 microsecond, are polarization and temperature dependent. Furthermore, the best AOTF consumes several watts of RF power, has spectral resolution about 3 nm between the adjacent channels (which is not adequate for current WDM requirements), and introduces over 5 dB loss because of fiber-to-chip mode conversions.

Another wavelength-sensitive optical switch may be implemented with a tunable Fabry Perot filter (TFPF). When the filter is aligned to a specific wavelength, it is transparent to the incoming optical power. Though the filter mirrors are almost 100% reflective no power is reflected back from the filter . With the wavelength changed or the filter detuned (for example, by tilting the back mirror), the filter becomes almost totally reflective. With the optical circulator in front of the filter, the reflected

power may be redirected from the incident port. The most advanced TFPF with mirrors built into the fiber and PZT alignment actuators have only 0.8 dB loss. The disadvantage of these filters is a need for active feedback and a reference element for frequency stability.

A VOA is an opto-mechanical device capable of producing a desired reduction in the strength of a signal transmitted through a optical fiber. Ideally, the VOA should produce a continuously variable signal attenuation while introducing a normal or suitable insertion loss and exhibiting a desired optical return loss. If the VOA causes excessive reflectance back toward the transmitter, its purpose will be defeated.

Although fixed band-rejection filters are readily available using Bragg or long-period gratings impressed into the core of an optical fiber there are no simple, adjustable all-fiber band-rejection filters. Such filters would vary the amplitude of signals within a fixed wavelength range.

Although a variable transmission band-rejection filter of sorts can be made by varying the center wavelength of a Bragg or long-period grating, as one channel is attenuated another channel is unavoidably strengthened.

Accordingly, there is a need for a tunable band-rejection filter that changes its amplitude transmission over a specified wavelength range. There is a further need for a tunable band-rejection filter that has a reduced power consumption requirement for tuning. There is yet a further need for a tunable band-rejection filter that has a low insertion loss.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide an improved tunable band-rejection filter.

Another object of the present invention is to provide a tunable band-rejection filter that has a reduced power consumption requirement for tuning.

A further object of the present invention is to provide a tunable band-rejection filter that has a low insertion loss.

Yet another object of the present invention is to provide a tunable band-rejection filter that is small and compact.

A further object of the present invention is to provide a tunable band-rejection filter that has a fast response time.

These and other objects of the present invention are achieved in a dynamic gain flattening filter that includes a first filter stage. The first filter stage has a first tunable coupling member and a first differential delay with first and second tunable delay paths. The first tunable coupling member adjusts an amount of power of the optical signal that is divided onto the first and second tunable delay paths of the first differential delay.

In another embodiment of the present invention, a dynamic gain flattening filter includes a first filter stage and a first polarization splitter. The first filter stage has a first tunable coupling member and a first differential delay with first and second tunable delay paths. The first tunable coupling member adjusts an amount of power of the optical signal divided onto the first and second tunable delay paths of the first differential delay. The first polarization splitter splits the optical signal into two orthogonal polarizations.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a schematic diagram of one embodiment of a dynamic gain flattening filter of the present invention.

Figure 2 is a schematic diagram of one embodiment of tunable coupling members from Figure 1 with liquid crystal alignment members coupled to a voltage source.

Figure 3 is a schematic diagram of one embodiment of tunable delays from Figure 1 with liquid crystal alignment members coupled to a voltage source.

Figure 4 is a schematic diagram of an embodiment of a dynamic gain flattening filter of the present invention that includes polarization splitters.

DETAILED DESCRIPTION

Referring now to Figure 1, one embodiment of a dynamic gain flattening filter 10 of the present invention includes a first filter stage 12 with a first tunable coupling member 14 and a first differential delay 15 with first and second tunable delay paths. First tunable coupling member 14 adjusts an amount of power of the optical signal that is divided onto the first and second tunable delay paths of first differential delay 15.

First differential delay 15 can include fixed portion and tunable portions. Alternatively, first differential delay 15 can have a first fixed differential delay 16 and a first tunable differential delay 18 with the first and second tunable delay paths. First fixed differential delay 16 sets a periodic variation in a power spectrum of the optical signal. First tunable differential delay 18 sets a phase of the periodic variation in the power spectrum of the optical signal.

First fixed differential delay 16 can be a birefringent material such as $LiNbO_3$, TiO_2 or calcite. Tunable differential delay 18 can be a liquid crystal cell that changes the differential delay between the two delay paths.

First tunable coupling member 14 can be a liquid crystal cell that rotates the polarization angle of a linear input polarization.

First fixed differential delay 16 can be positioned between first tunable coupling member 14 and first tunable differential delay 18. First tunable differential delay 18 can be positioned between first tunable coupling member 14 and first fixed differential delay 16. The positions of first fixed differential delay 16 and first tunable differential delay can be switched.

Filter 10 can include one or more additional stages. For example, a second stage 20 can be coupled to first stage 12. Second stage 20 has a second tunable coupling member 22 and a first differential delay 23 with first and second tunable delay paths. Second tunable coupling member 22 adjusts an amount of power of the optical signal that is divided onto the first and second tunable delay paths of second differential delay 23.

Second differential delay 23 can include fixed and tunable portions. Alternatively, second differential delay 23 can have a second fixed differential delay 24 and a second tunable differential delay 26 with the first and second tunable delay paths. Second fixed differential delay 24 sets a periodic variation in a power spectrum of the optical signal. Second tunable differential delay 26 sets a phase of the periodic variation in the power spectrum of the optical signal.

Second fixed differential delay 24 can be positioned between second tunable coupling member 22 and second tunable differential delay 26. Second tunable differential delay 26 can be positioned between second tunable coupling member 22 and second fixed differential delay 24. Again, the position of second fixed differential delay 24 and second tunable differential delay 26 can be changed.

Additional stages can be added and provide more detailed filtering of the optical power spectrum. In one embodiment, filter 10 includes at least 4 or 5 stages.

Each differential delay 16, 18, 24 and 26 is polarization dependent. First and second fixed differential delays 16 and 24 each generate a time delay between first and second polarizations of the optical signal. First and second tunable differential delays 18 and 26 change an optical phase between first and second polarizations of the optical signal. First and second tunable coupling members 14 and 22 can be polarization state transformers that transform the incoming signal beam from one polarization state to a different polarization state. First and second tunable differential delays 18 and 26 modify first and second polarizations of the optical signal with different phase relationships.

In one embodiment, illustrated in Figure 2, first and second tunable coupling members 14 and 22 can include first and second liquid crystal alignment members 28 and 30 coupled to a voltage source 32. Liquid crystals in contact with first and second liquid crystal alignment members 28 and 30 can be orientated, (i) at different angles with respect to each other, (ii) at the same angles with respect to each other or (iii) at an orthogonal angle with respect to each other.

As illustrated in Figure 3, first and second tunable differential delays 18 and 26 can include first and second liquid crystal alignment members 34 and 36 coupled to a voltage application member 38. Liquid crystals in first and second liquid crystal alignment members 34 and 36 are orientated, (i) at the same angle with respect to each other, (ii) at different angles with respect to each other or (iii) at an orthogonal angle with respect to each other.

One or both of first and second tunable coupling members 14 and 22, and first and second tunable differential delays 18 and 26 can be, (i) a liquid crystal tuning element, (ii) a Faraday rotation member, (iii) an electro-optic member or (iv) a thermal tuning member.

In another embodiment, illustrated in Figure 4, filter 10 can also include a first polarization splitter 40 positioned adjacent to first filter stage 12. First polarization splitter 40 splits the optical signal into two orthogonal polarizations along paths A and B. First polarization splitter 40 can be a polarization walk-off crystal made of materials including but not limited to $LiNbO_3$, TiO_2 or calcite. First polarization splitter 40 can either split the two polarization states using spatial or angular walk-off.

A second polarization splitter 42 can be positioned adjacent to first stage 12. Second polarization splitter 42 combines the two orthogonal polarization paths A and B to create a dynamic tunable gain flattening filter 10 that has a transmission substantially independent of the input polarization state of the optical signal.

A first half-wave plate 44 can be positioned between first polarization splitter 40 and first stage 12 at one side and a second half-wave plate 46 can be positioned at the other side. First half-wave plate 44 alters one or both of the input polarizations to create two identical polarization states that travel independently through dynamic tunable gain flattening filter 10. Second half-wave plate 44 flips the polarizations so they are orthogonal and can be combined by second polarization splitter 40.

Second stage 20, and additional stages can also be included in the Figure 4 embodiment. Second polarization splitter 42 can be positioned adjacent to second stage 20. Second polarization splitter 42 can be positioned between second stage 20 and second polarization splitter 42.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. It is intended that the scope of the invention be defined by the following claims and their equivalents.

What is claimed is: